A Summary on the Cryogenic Performance of Various Types of Resistors

Scope

Electronics capable of operation at extremely low temperatures are anticipated in NASA missions such as planetary exploration and deep space probes. These electronics include passive and active devices, power generation and conditioning modules, and application-specific integrated circuits, to name a few. The availability of low temperature electronics will improve reliability, increase energy density, improve efficiency, decrease size and weight, and extend the operational lifetimes of space-based electronic systems. To address some of these requirements, several types of standard and power resistors were investigated for potential use in low temperature environments. This work was performed at the NASA Glenn Research Center in support of the NASA Electronic Parts and Packaging (NEPP) Program. It is anticipated that the results of this and other research efforts will be utilized to aid in the proper design and selection of components for the development of electrical and electronic systems that are geared for low temperature operation with good reliability and high efficiency.

Test Procedure

Several types of low to medium power resistors were evaluated in terms of resistance stability as a function of temperature. These passive devices included metal film, carbon and ceramic composition, thin and thick film, wire wound, and power film resistors. Manufacturer specifications of these resistors are listed in Table I. Two values of each type of resistor were selected in this evaluation. These values were 10 Ω (or closest value if unavailable) and 1 kΩ. For each type of resistor, two devices of the same value were included in this work to confirm certainty and validity of the performance of the resistor under test. The resistors were evaluated in the frequency range of 10 Hz to 500 kHz using four-wire measurements at various test temperatures between +25 °C and -190 °C. The test temperatures were: 25 °C, 0 °C, -25 °C, -50 °C, -75 °C, -100 °C, -125 °C, -150 °C, -175 °C, and -190 °C. Limited thermal cycling testing was also performed on the resistors. These tests consisted of subjecting the devices to a total of five thermal cycles between +25 °C and -190 °C.

Results and Discussions

As was mentioned before, two devices of the same value for each type of resistor were evaluated in this work. These paired devices have shown exactly the same behavior in their characteristics with temperature. Therefore, data pertaining to only one of each type of resistor of a specific value are presented.

Metal Film

The 10 Ω metal film resistor displayed excellent stability with temperature as its value remained steady throughout the test temperature range. The 1 kΩ version of this type of resistor, however, exhibited a gradual, but very slight, increase in resistance as temperature was decreased. This increase in resistance amounted to only about 0.3% at – 190 °C.

Table I. Manufacturer specifications of resistors.

Type	Value (Ω)	Tol. (%)	Voltage (V)	PWR (W)	Temp (°C)	Temp Coeff (ppm/°C)	Package	Manufacturer	Part #
Metal Film	10	±1	250	0.5	-55 to +175	±25 to ±200	Axial	Vishay/Dale	CMF55C10
	1K	±1	250	0.5	< +170	±50	Axial	Vishay	CT551K0FT2
Wire Wound	10	±5	495	5	< +350	±30	Axial	Ohmite	95J10R
	1K	±5	495	5	< +350	±30	Axial	Ohmite	95J10K0
Thin Film	33	(±1 Ω)	200	1.6	-55 to +125	±250	Single-in-line	Bourns	4608X-102-330
	1K	±2	200	1.6	-55 to +125	±100	Single-in-line	Bourns	4608X-102-102
Thick Film	100	±2	100	0.3	-55 to +125	±100	Single-in-line	Dale	CSC08A-03-101G
	1K	±2	100	0.2	-55 to +125	±100	Single-in-line	Dale	CSC08A-01-102G
Carbon Film	10	±5	250	0.25	< +155	±350	Axial	Ohmite	OK1005
	1K	±5	250	0.25	< +155	-450	Axial	Ohmite	OK1025
Carbon Composition	15	±5	250	0.25	< +130	--	Axial	Ohmite	OD150J
	1K	±5	250	0.25	< +130	--	Axial	Ohmite	OD102J
Ceramic Composition	10	±10	500	1	< +200	-1300±300	Axial	Ohmite	OX100K
	1K	±10	500	1	< +200	-1300±300	Axial	Ohmite	OX102K
Power Film	10	±1	300	20	-55 to +175	-20 to +50	TO-220	Caddock	MP820-10.0-1
	1K	±1	300	20	-55 to +175	-20 to +50	TO-220	Caddock	MP820-1.0K-1

Wire wound

The resistance and the percentage change of both the 10 Ω and the 1 kΩ wire wound resistors seemed to exhibit very slight decrease in their resistance as temperature was decreased. The drop in the resistance at –190 °C for the 10 Ω resistor was about 1%, while that of the 1 kΩ resistor reached only 0.6%.

Thin Film

Unlike the wire wound resistors, these types of resistors experienced an increase in their resistance with decrease in temperature. While this increase approached only 3.8% for the 33 Ω resistor at the extreme low temperature, it did not exceed 1.4% for the higher value resistor.

Thick Film

The resistance of the 100 Ω thick film resistor underwent an increase as the test temperature was decreased. At –190 °C, for example, this increase amounted to about 5.5%. Although the 1 kΩ resistor displayed a trend similar to that of the 100 Ω resistor with temperature, its increase in resistance, however, did not exceed 0.5% at the lowest temperature.

Carbon Film

Both of these resistors showed exact behavior with temperature as their resistance increased gradually as the temperature was decreased. The increase in the resistance, for either resistor, i.e., 10 Ω and 1 kΩ, amounted to little over 5% at temperature of –190 °C.

Carbon Composition

Similar to their film counterpart, the carbon composition resistors also exhibited an increase in resistance as the test temperature was reduced. The increase in resistance, however, is more significant as it approached 12% for the 15 Ω resistor, while it fell in the vicinity of 28% for the 1 kΩ device. Both of these occurred at the lowest test temperature of – 190 °C.

Ceramic Composition

The behavior of the ceramic composition resistors with temperature seemed to resemble that of the carbon composition resistors in terms of change polarity and magnitude. The 10 Ω as well as the 1 kΩ ceramic composition resistors experienced appreciable change in their resistance values as temperature was decreased. The increase in the resistance, for either resistor, was about 16% at the extreme low temperature.

Power Film

Both power film resistors exhibited an increase in their resistance with decreasing temperature. The magnitude of this resistance increase occurring at – 190 °C, for either one of these two resistors, was in the range between 4% and 5%.

The resistance and percentage change occurring at –190 °C for all resistors are shown in Table II. For illustrative purposes, only measurements taken at test frequency of 1 kHz are presented. The manufacturer's specified values as well as the values measured at room temperature are also listed in Table II. It can be clearly seen that the metal film, wire wound, and thin film resistors have displayed excellent stability in their resistance with change in temperature. Both the carbon and the ceramic composition resistors, on the other hand, have exhibited significant increase in their resistance as the test temperature was decreased. The low temperature-induced changes exhibited by the three remaining types of resistors, which were film-based, i.e. power, thick, and carbon, investigated in this work were not as severe and their performance was in between the other two groups.

Table II. Resistance and percentage change at –190 °C (@ 1 kHz).

Type	Value (Ω)	Resistance (Ω) at 25 °C	Resistance (Ω) at -190 °C	Change in Resistance (%) at -190 °C
Metal Film	10	10.00	9.99	0.0
	1K	999.15	1001.86	0.3
Wire wound	10	9.70	9.62	-0.9
	1K	984.80	979.31	-0.6
Thin Film	33	33.07	34.32	3.8
	1K	995.41	1007.88	1.3
Thick Film	100	99.99	105.42	5.4
	1K	998.70	1003.22	0.5
Carbon Film	10	9.96	10.46	5.1
	1K	980.30	1035.83	5.7
Carbon Composition	15	14.65	16.34	11.6
	1K	1013.29	1296.54	28.0
Ceramic Composition	10	9.49	10.99	15.8
	1K	993.09	1167.51	17.6
Power Film	10	10.00	10.48	4.9
	1K	996.20	1037.06	4.1

To determine the effect of extended low temperature exposure, the resistors were subjected to limited thermal cycling. The devices were thermally cycled for a total of five cycles in the temperature range of 25 °C to -190 °C. A temperature rate of 10 °C/min was used with a soak time of 20 minutes at both the room and the -190 °C temperatures. The values of the resistance of all resistors at room temperature, for both the pre-cycling and post-cycling conditions, are listed in Table III. It can be clearly seen that all resistors exhibited no change due to this limited thermal cycling as they retained their resistance values.

Conclusion

Passive as well as active electronic components capable of low temperature operation constitute a key requirement for the development of advanced and reliable power and communication systems for space applications. Eight types of resistors were investigated for their potential use in extreme temperature environments. The resistors were characterized in terms of their resistance stability between 25 °C and –190 °C in the frequency range of 10 Hz to 500 kHz. Limited thermal cycling was also performed on the resistors in the same temperature range. While some of these resistors showed excellent stability with temperature, others did not fare as well. Table IV gives a graphical illustration of the resistor type and the corresponding change in resistance at the extreme low temperature of –190 °C. More comprehensive testing, however, is required to fully characterize the behavior of these and other devices to determine their suitability and limitation in low temperature environments. Issues such as thermal cycling under long-term exposure and multi-stress conditions will need to be carried out for a complete assessment of the performance and reliability of these devices.

Table III. Resistance before and after five thermal cycles (@ 1 kHz).

Type	Value (Ω)	Resistance (Ω) at 25 °C Pre-cycling	Post-cycling
Metal Film	10	10.00	10.00
	1K	999.15	999.30
Wire wound	10	9.70	9.70
	1K	984.80	984.79
Thin Film	33	33.07	33.06
	1K	995.41	995.01
Thick Film	100	99.99	99.98
	1K	998.70	998.68
Carbon Film	10	9.96	9.96
	1K	980.30	980.13
Carbon Composition	15	14.65	14.78
	1K	1013.29	1015.93
Ceramic Composition	10	9.96	9.95
	1K	993.09	992.31
Power Film	10	10.00	9.99
	1K	996.20	996.01

Table IV. Percent change in resistance at –190 °C versus resistor type.